TN 295
.U4

No. 9098
2nd Set

THE LIBRARY OF CONGRESS

THE LIBRARY OF CONGRESS

IC 9098

Bureau of Mines Information Circular/1986

LIBRARY OF CONGRESS
4
OCT 2 1986
COPY
EXCHANGE & GIFT DIVISION

Antimony Availability—Market Economy Countries

A Minerals Availability Appraisal

By C.M. Palencia and C.P. Mishra

UNITED STATES DEPARTMENT OF THE INTERIOR

Information Circular 9098

Antimony Availability—Market Economy Countries

A Minerals Availability Appraisal

By C.M. Palencia and C.P. Mishra

UNITED STATES DEPARTMENT OF THE INTERIOR
Donald Paul Hodel, Secretary

BUREAU OF MINES
Robert C. Horton, Director

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environment and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

TN295
.U4
no. 9098
2nd set

Library of Congress Cataloging in Publication Data

Palencia, Cesar M.
Antimony availability—market economy countries.

(Information circular/Bureau of Mines ; 9098)

Bibliography: p. 20

Supt. of Docs. no.: I28.27:9098

1. Antimony. I. Mishra, C.P. (Chamundeshwari P.) II. Title. III. Series: Information circular (United States. Bureau of Mines) ; 9098.

TN295.U4 [TN490.A6] 622 s [338.2'747] 86-600191

PREFACE

The Bureau of Mines is assessing the worldwide availability of selected minerals of economic significance, most of which are also critical minerals. The Bureau identifies, collects, compiles, and evaluates information on producing, developing, and explored deposits, and on mineral processing plants worldwide. Objectives are to classify both domestic and foreign resources, to identify by cost evaluation those demonstrated resources that are reserves, and to prepare analyses of mineral availability.

This report is one of a continuing series of reports that analyze the availability of minerals from domestic and foreign sources. Questions about, or comments on, these reports should be addressed to Chief, Division of Minerals Availability, Bureau of Mines, 2401 E St., NW., Washington, DC 20241.

CONTENTS

ILLUSTRATIONS

TABLES

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

°F	degree Fahrenheit	min	minute
ft	foot	mt	metric ton
g/mt	gram per metric ton	mt/d	metric ton per day
h	hour	mt/yr	metric ton per year
kg	kilogram	mtu	metric ton unit
kg/mt	kilogram per metric ton	ppm	part per million
km	kilometer	tr oz	troy ounce
lb	pound	yr	year
m	meter		

ANTIMONY AVAILABILITY—MARKET ECONOMY COUNTRIES

A Minerals Availability Appraisal

By C. M. Palencia[1] and C. P. Mishra[2]

ABSTRACT

The Bureau of Mines studied the potential availability of primary antimony (Sb) from demonstrated resources in 21 mines and deposits in market economy countries (MEC's). Twelve of these properties were evaluated as producers and nine as non-producers. The 21 studied properties contain 499,600 mt Sb as demonstrated resources, of which 304,000 mt is recoverable as antimony metal; another 973,500 mt Sb is contained in inferred resources.

Recoverable antimony from demonstrated U.S. deposits is only 10,700 mt, just 3.5 pct of the MEC total. Domestic production of primary antimony from operating mines has averaged only 561 mt/yr over the 10-yr period 1975-84. This represents just over 5 pct of total U.S. consumption of primary antimony, which averaged 11,081 mt/yr during the same period. The United States will thus continue to rely on imported ores and/or concentrates, antimony oxides, and metal to satisfy domestic industrial requirements.

At production costs up to $1.15/lb Sb, 110,000 mt of refined antimony is potentially available from 10 of the 21 studied properties. At $2/lb, 294,000 mt Sb is available, and at $3/lb, the total rises to 304,000 mt Sb available from all evaluated producers of refined antimony.

[1]Mining engineer.
[2]Supervisory physical scientist.
Minerals Availability Field Office, Bureau of Mines, Denver, CO.

INTRODUCTION

This Bureau of Mines study provides an analysis of the geological, engineering, economic, and other factors that influence the availability of primary antimony. A number of small producers in Bolivia and Mexico were not included in the analysis because of inadequate information concerning production and resource availability.

Production costs of antimony metal and antimony trioxide (Sb_2O_3) are not significantly different. In this study, antimony metal and Sb_2O_3 are considered the final marketable products. Antimony is recovered either as a primary product or as a byproduct of other metal, mostly at the smelter. Antimony as a metal is also recovered from the recycling of scrap metal (mostly battery scrap). However, in this study, only those mines and deposits from which antimony is or can be produced as a primary product have been analyzed.

Byproduct and secondary antimony were not analyzed, because it is not possible to track down the sources from which these products are being recovered. Moreover, recovery of antimony as a byproduct is incidental to the production of other metals. Significant domestic antimony production comes from silver processing to eliminate antimony penalty.

Production of secondary antimony mostly is incidental to the recycling of other metals in which antimony is an alloy. Antimony is used mainly as an alloy for lead (antimonial lead alloy for battery) with or without other metals. Therefore, the recovery of secondary antimony depends mainly on the extent to which lead is recycled.

Estimate of total world antimony resources are conflicting and vary from one source to another. These sources are, however, in consensus that more than half of the total world's antimony resources are located in China. In 1983, the United States imported about 50 pct of its antimony metal requirements from China.

Antimony resources located in Soviet Union, China, and other centrally planned economy countries (CPEC's) were not analyzed in this study. Production cost estimates could not be supported because of the difficulty in collecting quantitative resource information. This study consolidates past work and recent information from numerous sources as of January 1984. Current and potential antimony availability data are presented in this study.

COMMODITY OVERVIEW

PRODUCTS AND USES

Antimony is primarily used in its metallic form as an alloying element to increase strength and inhibit chemical corrosion, such as in antimonial lead used in lead-acid storage batteries. This application has been substantially replaced by lead-calcium maintenance-free batteries. The effect of lead-calcium batteries is reflected in the decline in the antimonial lead consumption from 6,578 mt Sb in 1974 to 766 mt Sb in 1984 (table 1). However, recent findings show that lead-calcium batteries have a shorter life than those using antimony. The Battery Council International in Chicago reported in May 1982, that the average life for the lead-calcium batteries had been 27.3 months compared with 36.7 months for the lead-antimony batteries (*1*).[3] This may allow antimony-alloyed battery grids to regain part of the battery market (*2*). Any recovery is expected to remain small and probably will not attain the consumption

[3]Italic numbers in parentheses refer to items in the list of references at the end of this report.

Table 1.—Reported industrial consumption of primary antimony in the United States by end use, 1974–84
(Metric tons contained antimony)

	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
Metal products:											
Ammunition	110	217	57	125	121	229	328	371	267	159	W
Antimonial lead	6,578	4,144	3,502	2,663	2,569	1,179	678	1,140	719	840	766
Bearing metals and bearings	432	365	367	240	253	213	202	187	130	130	153
Cable covering	15	21	17	15	19	15	28	22	23	28	W
Castings	28	16	22	12	13	13	9	10	8	8	10
Collapsible tubes and foil	16	8	21	15	15	22	16	8	1	W	W
Sheet and pipe	63	54	67	51	35	33	26	33	24	39	73
Solder	186	121	171	200	187	180	122	95	112	140	207
Type metal	97	68	72	75	73	34	19	17	10	9	28
Other	122	109	149	94	102	90	67	63	61	64	306
Total	7,647	5,123	4,445	3,490	3,387	2,008	1,496	1,946	1,355	1,417	1,543
Nonmetal products:											
Ammunition primers	10	13	12	12	12	21	18	23	18	15	19
Ceramics and glass	1,256	897	1,143	1,403	1,142	1,022	1,182	709	1,232	1,136	1,172
Fireworks	10	9	11	8	4	5	3	3	5	4	6
Pigments	417	291	376	363	372	362	453	309	299	180	161
Plastics	1,298	990	1,158	1,363	1,321	1,433	1,484	1,407	952	901	1,005
Rubber products	602	415	524	429	230	165	295	210	200	63	19
Other	1,150	596	1,206	241	150	126	97	101	94	108	145
Fire retardants	3,976	3,446	5,036	5,230	5,310	5,517	5,166	5,806	4,383	5,628	7,219
Total	8,719	6,657	9,466	9,049	8,541	8,651	8,698	8,568	7,183	8,035	9,746

W Withheld to avoid disclosing proprietary data; included with "Other."

level of 1974, since the antimony content used in antimony-lead batteries had been dropping; e.g., in 1972 antimonial lead batteries used 6 pct Sb, but in 1977 the antimony content dropped to 4 pct (*1*). Lead-antimony alloy also finds industrial use in tank linings, chemical pumps and pipes, roofing sheets, and cable sheaths. When alloyed with tin, antimony forms hard crystals that increase bearing life. In general, antimony is added to other metals or alloys to increase hardness, reduce shrinkage, and promote sharp definition in castings.

The nonmetallic consumption of antimony, the larger portion of the total consumption, is primarily in flame retardants. Sb_2O_3, the most commonly used antimony compound in the manufacture of flame retardant, is not a fire retardant per se. However, when combined with halogens such as chlorine and bromine, a synergistic reaction occurs and the resulting halogenated mixtures become a very effective fire retardant. At this time, no satisfactory theory has yet been advanced to explain the synergistic effect of halogens and Sb_2O_3 as flame retardants.

Other antimony compounds used in the manufacture of flame retardants are antimony pentoxide (Sb_2O_5) and sodium antimonate ($NaSbO_3$). Both are products of oxidation of Sb_2O_3. Sb_2O_5, because of its lower opacity, is extensively used in textile industry, while $NaSbO_3$, because of its higher opacity, is used in products with dark color.

Information in table 1 shows the use of antimony compounds in fire retardant applications is high. Other antimony compounds used in the industry include antimony pentasulfide (Sb_2S_5), used as vulcanizing agent; antimony trisulfide (Sb_2S_3), used as primer in ammunition and as smoke markers; and antimony trichloride ($SbCl_3$), used as medicine and a catalyst.

SUBSTITUTES

In recent years, the use of antimonial lead in the United States declined sharply owing to the introduction of the lead-calcium battery grids in maintenance-free batteries. In the United Kingdom, and probably other Western European countries, the change from lead-antimony to lead-calcium has not progressed. This is because of the different production techniques used in each country. Battery grids manufactured in the United States are produced by expanding and pressing methods, while in the United Kingdom, the grids are produced by castings. Lead-calcium alloys are not amenable to casting techniques.

Antimony had been used as an opacifier for enamel and pigments for paints and lacquers. Titanium, zirconium, lead, zinc, chromium, and tin may be substituted for this application. As a hardening agent for lead, antimony can be replaced by tin, calcium, cadmium, selenium, and sulfur. Selected organic compounds and aluminum oxides are widely accepted alternative materials in flameproofing. Plastic and aluminum are gaining acceptance as cheap substitutes for cable sheathings.

U.S. PRODUCTION, CONSUMPTION, AND TRADE

U.S. production, consumption, and trade of primary antimony (1975-84) are shown in table 2. Primary domestic antimony production is from Stibnite Hill (Babbitt) Mine in Montana. The Sunshine Mine in Idaho, although producing a larger tonnage than Stibnite Hill Mine, was not analyzed, because the antimony produced in this mine is a byproduct of its silver recovery. Antimony byproduct produced in domestic lead smelters has no definable resource base. In addition, the smelter feed is generally from a number of mines (both domestic and foreign); thus, the antimony cannot be identified with any particular resource base. Any analysis of byproduct antimony, therefore, would be erroneous.

Reported domestic consumption of primary antimony averaged 11,081 mt/yr of contained antimony over the 10-yr period (table 2). The consumption of primary antimony has declined in recent years, primarily due to the reduced amount of antimonial lead consumption in automotive batteries. On the other hand, the use of Sb_2O_3 in flame retardant applications has been increasing and expanding especially in plastic, textile, rubber, and pigment products. This increase is expected to offset the decline in use experienced in the battery industry.

Since there are no significant changes foreseen in the mining of domestic antimony, the United States will continue to depend on foreign sources for antimony ores, concentrates, oxides, and metal. Currently, the United States imports about 95 pct of the total industrial requirements, mostly from Bolivia, Mexico, South Africa, and China (*3*). The United States exports insignificant amounts of antimony metal, alloys, and scrap, averaging only 443 mt/yr contained Sb over the last 10-yr period.

MARKET STRUCTURE

Antimony is sold as ores, concentrates, metals, trioxides, and to a minor extent, as antimony products such as antimonial lead, Sb_2S_3, and other compounds. Among MEC's, South Africa and Bolivia are the major suppliers not only of ores and concentrates but also of metals and trioxides.

Table 2.—Salient antimony statistics, 1975–84
(Metric tons contained antimony)

	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984[p]
United States:										
Primary production:										
Mine	803	257	553	724	655	311	586	456	760	505
Smelter	11,056	13,259	11,634	12,798	13,662	14,569	16,185	11,140	13,206	15,403
Secondary production	16,294	17,958	27,756	23,996	21,909	18,044	18,010	15,053	12,883	14,432
Export of metal and alloys	308	309	673	504	440	411	294	753	276	463
Import for consumption (antimony content)	16,967	19,746	12,095	15,882	20,083	16,323	16,299	12,142	11,687	20,942
Reported consumption, primary antimony[1]	11,780	13,911	12,539	11,929	10,660	10,194	10,514	8,539	9,450	11,289
Stocks: Primary antimony, all classes (antimony content), Dec. 31	13,566	13,669	7,792	7,439	6,480	7,629	8,307	5,418	3,569	6,273
World production	69,945	64,762	67,676	61,897	63,056	63,510	57,584	53,766	50,372	53,394

[p]Preliminary.
[1]Includes primary antimony content of antimonial lead refineries.

Table 3 identifies the major sources of antimony production capacity by product type. Total antimony production capacity in all forms is estimated at 61,500 mt. Bolivia, the largest producer of ores and concentrates, oxides, and metal, has a capacity of about 15,500 mt/yr of ore and concentrates, 5,000 mt/yr of metal, and 1,000 mt/yr Sb_2O_3. South Africa produces about 13,500 mt/yr of ore and concentrates and 6,000 mt/yr of crude antimony trioxide with a purity of 81 to 83 pct Sb_2O_3, although a purer form grading about 97 pct Sb_2O_3 is also being produced (*2*).

Table 3.—Estimated antimony annual production capacities

(Metric tons contained antimony)

	Ore and concentrates	Trioxide	Metal
Australia	1,200	0	0
Bolivia	15,500	1,000	5,000
Canada	5,900	0	0
Mexico	3,700	0	800
Morocco	4,700	0	0
Republic of South Africa	13,500	6,000	0
Turkey	2,500	800	0
United States	0	[1]500	[1]400
Total	47,000	8,300	6,200

[1]Production may be consumed internally.

PRICE STRUCTURE

There is no specific antimony price structure in the international market. Actual prices are normally calculated by means of an agreed-upon formula between seller and buyer. The formula is based on the quality and form of the product sold. Published prices in trade journals are price ranges, which include not only the producer's price and dealer's price but also the assessed price for certain standard products based on the product information furnished by buyers and sellers (*1*). Occasionally the publication of a specific product price is suspended because information is insufficient to base an adequate assessment.

Ores and concentrates, the basic marketable antimony products, are sold in metric ton units of contained antimony. In recent years, the vertical integration of two major producing countries (Bolivia and the Republic of South Africa) has weakened the international trade in antimony concentrate. Trade journals suspended publishing prices for 50 to 55 pct Sb in concentrate in December 1976, although the prices for 60 pct Sb in sulfide ore are continued. Table 4 reflects concentrate price in international trade.

Table 4.—U.S. antimony prices, 1975–84

Year	Metal, $/lb[1]			Oxide, $/lb		Sulfide concentrate	Lump sulfide ore
	High	Low	Average	High	Low	(55 pct Sb), $/mtu	(60 pct Sb), $/mtu
1975	2.23	1.58	1.77	2.16	1.65	17.50–20.00	20.25–22.75
1976	1.75	1.58	1.65	1.80	1.65	20.50–22.30	23.70–25.25
1977	1.78	1.75	1.78	1.80	1.64	NA	18.87–22.00
1978	1.35	1.05	1.14	1.80	1.64	NA	16.92–18.07
1979	1.60	1.25	1.41	1.80	1.50	NA	21.04–22.39
1980	1.65	1.45	1.51	1.80	1.50	NA	23.50–25.00
1981	1.52	1.20	1.36	1.80	1.40	NA	20.50–22.50
1982	1.24	.93	1.07	1.80	1.20	NA	17.81–18.63
1983	1.35	.78	.91	1.20	1.00	NA	16.75–17.25
1984	1.77	1.20	1.51	1.80	1.16	NA	18.25–19.00

NA Not available.

[1]For years 1975–77 domestic producer price to RMM brand 99.5 pct Sb metal f.o.b. Laredo, TX. For years 1978–84, New York dealer price for 99.5 pct to 99.6 pct imported metal, c.i.f. U.S. port.

Sources: American Metal Market; Chemical Marketing Reporter; Metals Week; Metal Bulletin.

Antimony oxide prices published in trade journals have a wider range, partly because they include prices set by ASARCO, which are normally at the lower end of the range. The probable reason why ASARCO can maintain a competitive price is the fact that antimony produced by the company is only incidental to its lead smelting operation. Hence, most of its operating cost is tied to the lead recovery rather than to antimony. These antimony oxide price ranges are further complicated by the quality of specific oxided products; e.g., high-tint oxide costs less than low-tint oxide, while ultrapure oxide costs about $0.22/kg more than low-tint oxide.

Antimony metal price is quoted in several different ways. Aside from the producer's and dealer's prices, journals publish market prices for both the United States and the western European countries. Prices for these countries are expressed in terms of U.S. dollars per pound. Prices for Japan, on the other hand, are expressed in terms of yen per kilogram. The European market price generally is lower than the New York dealer's price.

GEOLOGY

Antimony distribution ranges from 0.2 to 0.5 ppm in the continental crust. In igneous rocks, the concentration ranges from 0.1 to 1.0 ppm with higher concentration noted in basaltic than in granitic rocks (*4*). Because of its strong affinity for sulfur and the metallic elements such as lead, copper, and silver, antimony is rarely found as native metal.

Normally associated with igneous activity, antimony deposits are genetically related to such intrusives as granites, diorites, and monzonites. Antimony ores are commonly found in quartzose veins, in pegmatites, and as replacements in limestone. Typical antimony deposits are small, irregular, and discontinuous bodies with grade sharply decreasing at depth. The geology of each primary antimony properties that were studied is discussed below.

DEPOSIT GEOLOGY

Australia

Hillgrove Mine

The Hillgrove Mine is located in northern New South Wales. The property has geographic coordinates of latitude 30°34′30″ S. and longitude 151°54′30″ E.

Stibnite mineralization occurs in low-temperature hydrothermal veins with quartz and calcite. The antimony occurrences are grouped into antimony, antimony-scheelite, and antimony-gold deposits. Some of the lode deposits are emplaced along granite dykes, though most are in

metasediments. The width of the lodes range from a few centimeters to a meter.

The principal antimony mineral is stibnite. Some of the associated minerals are pyrite-pyrrhotite, arsenopyrite, scheelite, graphite, and gold.

Effective mining operations in the area started in 1972 after Vam Ltd. acquired the property. To increase the ore resources, Vam Ltd. secured an agreement with Silver Valley Mineral N.L. to mine the Hillgrove area. From 1971 to 1976, the main mining activity was centered on Smith's, Freehold, and Garibaldi lodes, but in 1977 the operation was shifted and limited to the richer and more accessible Freehold Mine, because of the slump in antimony prices.

Wild Cattle Creek Mine

The Wild Cattle Creek Mine is also located in New South Wales. The geographic coordinates are 30°13′30″ S. and longitude 151°43′30″ E.

The antimony deposit lies within a sedimentary succession known as Fitzroy beds and consists of interbedded phyllites and metaquartzites. Regional metamorphism formed a strong foliation, which obliterated most traces of the original bedding. The deposit is situated near the center of a main shear zone. The best known antimony mineralization occurs in a lode having a strike length of about 335 m, a width of up to 14 m, and variable thickness from 2 m to 15 m. Stibnite mineralization has been found in minor quantities both east and west of the main deposit in subparallel shear zones with a total length of 5.5 km. Stibnite, the principal ore mineral, occurs with minor cinnabar, pyrite, and arsenopyrite.

Antimony was mined in the area from 1890 to 1892. Since then, several shafts were sunk and trenching was done, but due to low antimony price and high freight cost, the mining operation was not successful. In 1970, Australian Antimony NL acquired the ownership and brought the property into production in 1973; in 1977, however, it closed the mine operation and placed it under care and maintenance.

Bolivia

Candelaria Mine

Candelaria Mine is located in the southern part of Bolivia. The geographic coordinates are latitude 21°33′00″ S. and longitude 66°07′00″ W.

The Candelaria deposit occurs in shale, sandstone, and quartzite that has been folded into an anticline and syncline. Antimony is concentrated along the flanks and axis of the folds. The zone of mineralization is approximately 2,000 m long, 500 m wide, and has a variable width of a few centimeters to more than 1 m.

Discovered in the 1930's, the mine has been worked from time to time since 1945. Intermittent production occurred until 1970, when semimechanization was introduced. Since then, Empresa Minera San Juan Ltda. has operated the mine without interruption.

Caracota Mine

The Caracota Mine is located in the southern part of Bolivia. The geographic coordinates are latitude 20°05′00″ S. and longitude 65°55′00″ W.

The rocks consist of a series of slates, sandstones, quartzites, and schists. The strata have been folded into a series of anticlines and synclines. The most favorable mineral zone is the contact zone of the intercalated quartzite and shale. The major mineral zone has a strike length of 200 m, a width of 150 m, and a variable thickness that can exceed 3 m.

The principal ore mineral is stibnite, which is associated with quartz, pyrite, and arsenopyrite. Another accessory mineral is galena, which occurs in larger quantities at depth. The quantity of galena is insufficient for economic recovery and hinders antimony recovery. Gold is also found in some antimony veins.

Discovered before 1900, the mine was never extensively developed because of low antimony demand. Mining activities increased toward the end of World War II. Empresa Minera Unificada S.A. (EMUSA) acquired the mine in 1946 and mechanized the operation in 1965.

Chilcobija Mine

Chilcobija Mine is situated in the southern section of Bolivia. The approximate geographic coordinates are latitude 21°24′00″ S. and longitude 66°06′00″ W.

The deposit is related to a series of folds in a symmetrical anticline. Antimony vein structures formed in both flanks of the anticline, with the eastern flank more intensely mineralized. The predominant rock in the area is a sequence of laminated black shales intercalated with quartzite.

The primary ore forming mineral is stibnite, which is associated with small amounts of pyrite and quartz. The zone of mineralization has a length of 150 m, a width of 60 m, and a thickness varying from a few centimeters to 3 m. The mineralized zone contains an estimated in situ demonstrated resource of 376,300 mt averaging 4.77 pct Sb. An additional inferred resource of 284,900 mt, averaging 2.84 pct Sb, is indicated in the area.

Discovered in the early 1900's, the deposit was mined in a small and primitive way. After World War II, large-scale mining was initiated by EMUSA. Mechanization was introduced in 1960, and operation has continued without interruption since 1974.

Churquini Mine

Churquini Mine is located in southern Bolivia. The geographic coordinates are latitude 21°05′00″ S. and longitude 65°57′00″ W.

The area that comprises the Churquini property is on an anticlinal structure. Tectonic movements opened up major and minor fissures along, as well as transverse to, the anticlinal axis where subsequent antimony mineralization took place. Four types of ore deposits are found: (a) ore pockets along the axis, (b) small lenses intercalated with slate found along the crest, (c) ore deposits found along the flanks of the anticline, and (d) ore deposits along fractures. The mineralized zone has a length of 1,500 m and an average width of 40 m, and extends in depth to over 200 m. It is estimated that the zone contains a demonstrated resource grading 3.96 pct Sb.

Records show that the deposit has been worked since 1908 on a small scale. Santiago White acquired the property in 1930; he later sold the stocks to Cía. Metal Traders Overseas, who founded the Empresa Churquini Enterprises Inc. Anschutz Mining Corp., a U.S. company, bought the mine in 1979 but retained the name Churquini Enterprises Inc.

Espiritu Santo Mine

Espiritu Santo Mine is located in the southern part of Bolivia. The geographic coordinates are latitude 16°55′00″ S. and longitude 67°48′00″ E.

The Espiritu Santo deposit occurs in dark slippery mudstones and lies along the axis of a plunging anticline. The antimony occurs in two rock formations: the "Carne de Vaca," which is a compact mass of crystalline aggregates, and the "Acerada," which consists of fine, compact crystals. The zone of mineralization is composed of one primary and two secondary veins with a strike length of approximately 150 m, a width of 50 m, and variable thickness of up to 2 m. The antimony minerals occur as stibnite with pyrite, arsenopyrite, quartzite, and siderite as associated minerals.

The deposit was discovered in the 1920's and was worked in a small, primitive way from 1928 to 1957. In 1957 EMUSA acquired the property and mined it intermittently until 1970, when the operation was mechanized. Production continued without interruption from 1979 until 1982, when the mine was placed under care and maintenance.

La Salvadora Mine

The La Salvadora Mine is located in the central part of Bolivia. The geographic coordinates are latitude 17°30′00″ S. and longitude 66°55′00″ W.

Antimony minerals occur in quartz veins contained in micaceous black lutite. The quartz veins are observed and restricted to the "La Salvadora" fault. The zone of mineralization has a length of 300 m, a width of 50 m, and variable thickness of up to 0.5 m. The zone contained a demonstrated in situ resource of 58,998 mt in 1984. The principal veins, the San Juliano and the Progresso, are fractured mineral zones contained in lutite.

The principal ore mineral is stibnite, which is associated with quartz, pyrite, and arsenopyrite. The deposit was discovered in 1968 and was worked until January 1980, when the property was sold to Churquini Enterprises Inc.

Rosa de Oro Mine

Rosa de Oro Mine is located in the southern part of Bolivia. The geographic coordinates are latitude 21°41′00″ S. and longitude 66°07′00″ W.

The deposit occurs in sandstone, quartzite, and intercalated slate that have been folded into an anticline. The principal structure has a length of 3 km. Vein thicknesses vary from a few centimeters to 4 m. Near the surface level, lenses of ore can be observed, but at depth veins occur in irregular shapes. The principal ore lens at Rosa de Oro has a length of 75 m, a variable width of up to 4 m, and an average grade of 2.5 pct Sb.

The ore forming mineral is stibnite in association with quartz and pyrite. In some mineral zones, the stibnite has replaced the slate resulting in high antimony values. The deposit has a length of 100 m, a width of 35 m, and a variable thickness ranging up to 4 m. Additional inferred resources having an average grade of 2.5 pct Sb have been reported in the area.

The deposit was discovered at the turn of the century, and has been worked since 1905 in a small and primitive way. The original owners formed the current Empresa Minera Bernal Hermanos in the early 1970's, and operations have continued since 1976 without interruption.

Canada

Lake George Mine

Lake George Mine is located west of Fredericton, NB. Its approximate latitude is 45°52′00″ N. and its longitude 67°02′00″ W.

The antimony deposit lies southeast of the Hackshaw intrusion. Hydrothermal alteration effects were observed along numerous northerly and easterly trending fractures within the intrusion. Antimony veins occupy fracture zones that trend easterly and occur as lens-shaped bodies irregularly distributed throughout the zones. The dimensions of the irregular mineralized structures are approximately 1,250 m long, 550 m wide, and 550 m deep. The deposit is still open at depth. Diamond driling to a depth of about 550 m vertically indicates the vein structure continues into a siliceous skarn zone about 120 m thick. The zone contains abundant quartz stringers with stibnite and chalcopyrite blebs.

The main ore-forming minerals are stibnite and native antimony. Stibnite occurs in the eastern part of the deposit, whereas native antimony predominates in the western part of the deposit. Some native antimony is associated with uranium minerals. Tetrahedrite containing small exsolution blebs of chalcopyrite is present in small amounts. The most abundant metallic gangue minerals in the mine are arsenopyrite, pyrite, and pyrrhotite. Quartz and carbonates constitute the most abundant nonmetallic minerals.

Antimony was discovered in the Lake George area about 1863. The first recorded mine production occurred in 1880 and continued intermittently until 1890, when all operations were suspended. Between 1906 and 1970, sporadic mining operations would start up but would close shortly thereafter because of recurring arsenic problems and low antimony prices.

Consolidated Durham Mines & Resources Ltd. started a new mining initiative by exploring the area in 1970. Production began in 1971 at 180 mt/d ore. After a 6-month shutdown in 1972, operations were resumed until 1981, when low demand and poor metal prices once more forced its closure. The mine is presently under care and maintenance. It is quite likely that additional resources could be found in the area.

Italy

Manciano Mine

The Manciano Mine, one of the antimony mining units of Società per Azioni Minero-Metallurgiche (SAMIM) located in the Tuscany district, has a geographic location at about latitude 42°48′00″ N. and longitude 11°15′00″ E.

Ore deposits in the area are genetically related to magmatic activity. Postvolcanic manifestations such as steam jets and thermal springs are still active. The antimony minerals consist of stibnite in quartz bodies and are found at the contact between limestone and Tertiary sandstone. Structurally, the ore is localized by faults developed after the area was folded.

The only ore mineral found in quantity is stibnite; occasionally, some weathering products, oxides, hydroxides, hydrous calcium antimonates, and oxysulfides are found. The gangue mineral is mainly quartz, sometimes accompanied by traces of barite and fluorite. Ubiquitous calcite

and dolomite were derived from the country rock. Abundant gypsum is believed to be the product of supergene enrichment.

Antimony production in the Tuscany district started in the early part of the 19th century, but production ceased in the middle of the century. Records concerning early production are sparse and incomplete. Production resumed during both world wars and has been active since World War II.

Following World War II, the mining units were controlled by the AMMI Industrial Group. Exploration work by the company in 1950 led to the discovery of a new ore horizon. AMMI was a member of the EGAM Group, the state-controlled minerals agency that was abolished in 1978 under the same law that created SAMIM, the present operator.

Mexico

Wadley Mine

The Wadley Mine is located in the western section of La Sierra de Catorce in the State of San Luis Potosi. The approximate geographic coordinates of the mine are latitude 23°39′00″ N. and longitude 100°49′00″ W.

The stratigraphic sequence is represented by formations that have been identified in other locations. The older and more voluminous formation is the Zuloaga's calcareous bed, followed by the La Caja formation, both of which are from the Upper Jurassic period. The alluvium and conglomerate, the most recent deposits, are located in the eastern part of the area.

The important stratigraphic ore controls in concentrating the mineral are the permeability and the chemical reactivity of the host rock, which permit the circulation of solutions and precipitation of antimony minerals. The deposits, particularly the Wadley deposit, are believed to have formed from ascending hydrothermal solutions of magmatic origin.

The main ore-forming minerals are stibnite and cervantite (stibiconite). Gangue minerals are quartz, barite, fluorite, and calcite. Stibnite generally occurs in coarse-grained crystals. The ore deposits are in a series of lenses and as such have irregular proportions and indefinite dimensions.

Antimony was discovered in La Sierra de Catorce district in 1892. Since then, the area had been mined on and off for the last 92 yr. In 1969, the property leases and mine facilities were acquired by Cía. Minera y Refinadora Mexicana S.A. from NL Industries, Inc.

Morocco

Timerhdoudine Mine

Timerhdoudine Mine is located in the northeastern part of Kef-N'Sour mining district in central Morocco. The property has geographic coordinates of approximately latitude 32°59′00″ N. and longitude 5°59′00″ E.

The Kef-N'Sour mining district consists of highly folded, fractured, and faulted basement rocks of quartzite and schists. A fault bounding the block of the basement rock appears to be highly mineralized, especially where it is accompanied by quartzite. Two ore zones were identified in the area: Timerhdoudine No. 1 lode, measuring about 220 m long and 60 m wide, and Timerhdoudine No. 2 lode, measuring about 320 m long and 30 m wide. Mineral deposits within the two lodes occur at varying depths from about 50 m to 110 m below the surface with an average thickness of 60 m. The principal antimony mineral is stibnite with minor association of pyrite, barite, and quartz.

The Timerhdoudine deposit was discovered in 1960. Mining started on a small scale in 1973 and continued expanding to a production rate of 2,000 mt/yr. Based on a drilling program undertaken in 1981, a feasibility study recommends to expand the production capacity to 40,000 mt/yr starting in 1984.

Tourtit Mine

The Tourtit Mine is in the Atlas Mountain region of central Morocco with approximate geographic coordinates of latitude 32°29′00″ N. and longitude 5°50′00″ E. The region is underlain by silicified schists that were folded, fractured, and later faulted. Subsequent mineralization took place and formed a stockwork type of deposit. The ore deposit consists of a near-vertical slab.

The deposit measures about 300 m in length, has an average width of 12 m, and extends vertically some 150 m. The principal antimony mineral is stibnite, with minor associations of galena, pyrite, and quartz.

The antimony deposit was discovered as a result of a lead-zinc district discovery in 1960. Initial works consisted of a small-scale operation begun in 1978. Presently, the mine is under care and maintenance due to the depressed antimony metal price. Exploration work, which has continued at a modest rate since the mine was placed into production, has delineated substantial additional resources. A feasibility study done by a Yugoslavian engineering company showed that the mine should expand to a production level of 60,000 mt/yr ore.

Republic of South Africa

Consolidated Murchison Ltd. Mines

The Consolidated Murchison Ltd. (CML) antimony mines are located in the Letaba district of the northeastern Transvaal. The approximate geographic coordinates of the mines are latitude 24°00′00″ S. and longitude 31°31′00″ E. The antimony-producing mines are in the Murchison Range, a belt of sedimentary and carbonate rocks about 130 km long and 20 km wide. Antimony minerals are sparsely distributed along a shear zone. Local concentrations occur in fissures associated with vertical dragfolds.

The antimony mineral is mainly stibnite and some berthierite, which are considered medium-temperature hydrothermal minerals. The mineral zone also carries gold, cinnabar, and tetrahedrite. Though mineralization is not continuous, economically exploitable deposits are largely concentrated in a strike length of 13 km along the southern limb of a syncline.

Antimony mining in the area started during World War I. Unsuccessful recovery of the element by means of a liquation and leaching process caused production to cease soon after. In 1928, recovery of antimony was considered worthwhile as a byproduct of gold production. Since then, antimony production was slowly increased, and in 1943 antimony concentrate became the major product.

Antimony deposits in the area are unusually extensive by world standards. It is estimated that the ore zone will be productive for many years.

Thailand

Bo Thong Mine

Bo Thong Mine is located in the Chonburi Province. The deposit has geographic coordinates of latitude 13°11′00″ N. and longitude 101°41′00″ E. and is at an elevation of 100 m above sea level.

The general area consists of slightly metamorphosed Paleozoic rocks. Outcrops in the vicinity of the antimony deposit consist of sandstone, quartzite, and carboniferous shale striking northeast-southwest. The mineral zone is about 1,000 m long, 200 m wide, and 1 m thick. The deposit is composed of fragments and boulders of stibiconite, quartz, chalcedony, sandstone, and shale. The primary mineral is stibiconite with minor amounts of stibnite.

The deposit was discovered in 1977 along the border between Chonburi-Rayong and Chanthaburi-Chachoengsao Provinces. Detailed geological mapping and geochemical exploration surveys undertaken by the Thailand Department of Mineral Resources indicated extensive antimony mineralization along a belt 60 km long and 30 km wide. Weak market conditions for antimony metals caused exploration drilling on several anomalies to be postponed.

Doi Ngoem Mine

Doi Ngoem Mine (Ban Pin Antimony Mine) is located 5 km north of Ban Pin Phrae Province. The property has geographic coordinates of latitude 18°08′00″ N. and longitude 99°51′00″ E. at an elevation of 250 m above sea level.

The area is underlain by Permian to Triassic sedimentary rocks and by intrusive and extrusive igneous rocks. The Permian rocks, consisting of shale, sandstone, and conglomerate, are found in the eastern part of the area; the Triassic rocks, consisting of a volcanic series and composed of andesite, rhyolite, and agglomerate, are found in the western part. The antimony mineral occurs in quartz veins along breccia zones of quartzite and shale. The primary mineral is stibnite accompanied by significant amounts of arsenopyrite.

The ore zone is 100 m long and 15 m wide and extends approximately 50 m downward. The first mining lease in the area was initiated in 1974. At the time, mining was limited to exposed ore. The area has a high potential of additional antimony resource, but no systematic exploration has been conducted. The Thailand Department of Mineral Resources performed a detailed geological mapping and geochemical exploration; the anomalies discovered have yet to be drilled.

Mae Ta Mine

The Mae Ta (Mae Tha) Mine is located in Tambol Mae Ta Luang, Amphoe Chae Hom district, in the northern part of Lampang Province. The geographic coordinates are latitude 18°45′00″ N. and longitude 99°38′00″ E. at an elevation of 400 m above sea level.

The antimony deposits lie in a massive Permian limestone interbedded with shale, calcareous shale, and thin layers of sandstone and chert. The deposit occurs as veins in brecciated sediment layers, in large limestone pockets, or in disseminated bodies at or near limestone contact. The major ore minerals are stibnite and stibiconite. Exploration work in the area has been limited to surface outcrops.

Records of mining operations in the area are very limited. It has been reported that mining activity had been going on for many years on an intermittent basis. Since 1982 the mine is on care and maintenance due to depressed antimony metal prices.

Turkey

Turhal-Tokat Mines

The Turhal-Tokat Mines are located in central Anatolia Mountains of Turkey with approximate geographic coordinates of latitude 40°00′00″ N. and longitude 36°00′00″ E. The area is part of the metamorphosed Paleozoic schist zone of the northern Anatolia Mountains.

The main antimony ore vein strikes north-south, is about 1.5 km long, and has a variable thickness averaging about 2.0 m. The vein is cut by a large fault in the north. In the south, the vein disappears only to reappear about 1.5 km farther south, where it is also mined. The lower zone of the deposit contains large amounts of broken graphitic slate, which makes the antimony difficult and expensive to recover. The monomineralic vein indicates it was formed in a low-temperature environment.

An old mine drift and smelter, supposedly used by the Germans prior to World War I, indicates early mining activity. The mining rights to the area were given to Mr. Ragip Ozdemiroglu in 1933, who developed the property to the present state. Currently, there are six mines of which only three are in operation. A 200-mt/d mill, consisting of a preconcentration gravity circuit and a flotation section, was installed in 1963 with the intention of replacing the reverberatory smelter furnace; but it was finally decided to continue the production of antimony metal as well as concentrate.

United States

Stibnite Hill Mine

The Stibnite Hill Mine is in the Burns mining district, Sanders County, MT. The district is underlain by a unit of the Precambrian Belt consisting of the Missoula, the Piegan, and Ravalli Groups. The antimony-tungsten minerals are restricted to the rocks of the Prichard Formation of the Ravalli Group. The deposits are localized along numerous bedding plane fractures formed during Precambrian folding. Four distinct types of ore mineral occurrences have been identified with antimony as the most common metallic element. Secondary minerals as products of oxidation are kermesite, valentinite, cervantite, and stibiconite.

The antimony ore occurrence is predominantly controlled by thrust faulting that developed on the westward-dipping flanks of gently rolling folds. The veins have a thickness ranging from about 0.15 to 1.5 m. This erratic vein thickness contributes considerable mining dilution, causing a great downgrading of the ore value. Based on a 1.5-m mining width, the demonstrated ore resource in 1981 was estimated to contain an average of 3.59 pct Sb and 0.392 pct WO_3.

Stibnite was discovered in the Burns mining district in 1884, when the area was used as a route to Coeur d'Alene and the gold deposits in Idaho. Mine production was minimal through the turn of the century. The mine was idled soon after. Higher metal prices during World War II gave a new incentive for the development and production of antimony ore. The mine was closed in 1953 and reopened in 1972, just to close again in 1984.

Yellow Pine Mine

The Yellow Pine Mine is a single irregular deposit concentrated along the meadow creek shear zone in north-central Valley County, ID. Initial fracturing was extensive and preceded gold deposition.

Gold and antimony minerals occur principally in veinlets, stockworks, fissure fillings, and massive lenses. The principal antimony mineral is stibnite. Gold appears to be associated with pyrite and arsenopyrite, whereas silver is associated with antimony.

The antimony-rich area has the shape of a flat, upright funnel flaring on the surface at its widest diameter and tapering with depth. Gold is deposited around the antimony mineralization and extends down the neck of the funnel. The ore body as delineated is 200 m wide, 600 m long, and about 120 m deep. It contains a demonstrated resource of 1.6 million mt ore with grades averaging 1.09 pct Sb, 2.9 g/mt Au, and 18.9 g/mt Ag.

Mining in the Meadow Creek area began when gold was discovered in 1900. Mining activity at that time was not directed towards antimony. Antimony recovery with gold was initially recognized in 1929. Antimony production began in 1932 at a rate of 140 mt/d and peaked in 1945, when the mine capacity reached 1,814 mt/d. Mining operation continued at full production until 1952 when the end of the Korean war weakened the antimony demand.

MINERALOGY

Stibnite (Sb_2S_3) is the predominant mineral of antimony. In areas where stibnite is exposed, the mineral is weathered to various oxides of antimony such as the orthorhombic valentinite (Sb_2O_3), the isometric senarmontite (Sb_2O_3), stibiconite ($H_2Sb_2O_5$), and kermesite ($2Sb_2S_3.Sb_2O_3$).

The mineralogy of the deposits and the usually shallow occurrences suggest that the minerals were precipitated from low-temperature metal-bearing solution. Due to varied mineral occurrences, antimony deposits are classified into two genetic types: simple and complex.

Simple antimony deposits principally consist of stibnite or native antimony in siliceous gangue. The minerals are commonly associated with some pyrite and gold and small amounts of other metal sulfides. The stibnite is usually oxidized to one of the antimony oxide minerals. This type of deposit is found in Thailand, Mexico, and Bolivia. Complex antimony deposits usually consist of stibnite associated with pyrite, arsenopyrite, cinnabar, scheelite, and antimony sulfosalts, with varying amounts of copper, lead, and silver as well as the common sulfides of these metals and zinc. Ores of the complex deposits generally are mined primarily for lead, gold, silver, zinc, or tungsten. Deposits of this type are found in the United States, the Republic of South Africa, Australia, and Canada (*4*).

Of the more than 110 different antimony minerals, only stibnite and its oxidized equivalents and lead ores containing antimony yield substantial commercial quantities of the metal. Some of the more important antimony minerals are listed in table 5.

Table 5.—Antimony minerals

Mineral	Chemical formula	Antimony content, pct	Specific gravity
Antimony, native	Sb	100.0	6.7 –6.8
Cervantite	$Sb_2O_3.Sb_2O_5$	79.2	4.00–8.4
Jamesonite	$2PbS.Sb_2S_3$	29.8	5.5 –6.0
Kermesite	$2Sb_2S_3.Sb_2O_3$	83.5	4.5 –4.6
Livingstonite	$HgS.2Sb_2S_3$	55.3	4.81
Senarmontite	Sb_2O_3	83.5	5.2 –5.30
Stibiconite	$H_2Sb_2O_5$	74.8	5.1 –5.3
Stibnite	Sb_2S_3	71.7	4.52–4.62
Tetrahedrite	$3Cu_2S.Sb_2S_3$	29.8	4.4 –5.1
Valentinite	Sb_2O_3	83.5	5.0 –5.76

NOTE: Chemical formulas and specific gravities are from Dana (*5*).

RESOURCES

PRIMARY ANTIMONY

Due to the geological characteristics of antimony deposits, which are small, irregular, and discontinuous bodies, very few deposits are blocked out far ahead of the mining operation. Exploration and development are usually limited to a working reserve of a few years to minimize the excessive cost of blocking ore resources. In addition, the influence of the unstable price-market conditions of the metal further limits incentive to explore and develop extensive ore resources. Under such conditions, systematic evaluation of deposit resources is absent in most cases. Thus, considerable amounts of antimony resources are only speculative.

In this study, resources are included from 21 properties (table 6). The approximate location of each property is shown in figure 1.

Resource evaluations were performed at the demonstrated level as defined by the U.S. Geological Survey and the Bureau of Mines. Estimated resource tonnages aggregated by region, shown in table 7, were obtained from either individual company data, published data, or other resources.

The in situ demonstrated resources under study accounted for a total of 499,600 mt of contained antimony. An additional 973,500 mt Sb is available from inferred resources, though these resources were not included in economic analysis. Based on the demonstrated resources, Africa and Latin America account for about 65 pct of the total contained antimony (fig. 2). On the inferred level, combined resources from Latin America and "others" account for 80 pct (fig. 3) of the total contained antimony. The mines in "others," although containing smaller in situ resource tonnages than mines in Latin America and Africa, account for more than 48 pct of the total contained antimony, because they have high-grade ore deposits.

On a regional basis (table 7), the total recoverable antimony from the demonstrated resource is estimated at 304,000 mt, with Africa accounting for 50 pct of the total. North America is estimated to contain 10 pct of the total recoverable antimony of deposits studied. The remaining recoverable antimony is divided between Latin America and Asia-Australia at 23 pct and 17 pct, respectively.

The antimony resources in Australia come from two properties: the Hillgrove Mine and the Wild Cattle Creek Mine. Since areas below the present working level are com-

pletely unexplored, additional resource potential in the Hillgrove Mine is highly probable.

Eight producing mines in Latin America were economically evaluated—seven in Bolivia and one in Mexico. EMUSA, a privately held Bolivian company, operates three of the Bolivian mines: the Caracota, Espiritu Santo, and Chilcobija Mines. Churquini Enterprises Inc., a subsidiary of Anschutz Mineral Corp. (Denver, CO), operates the Churquini and Salvadora Mines. Rosa de Oro and Candelaria Mines are independently operated.

The only evaluated producing mine in Mexico is the Wadley Mine, which has been in operation for more than 90 yr. Due to the continuation of a prominent geologic feature present in the area, the inferred and demonstrated resources are expected to increase.

Table 6.—Deposits selected for evaluation

Deposit and location	Ownership	Status[1]	Mining type[2]
Australia:			
Hillgrove	New England Antimony Mines NL	P	U
Wild Cattle Creek	Antimony Australia NL	N	U
Bolivia:			
Candelaria	Empresa Minera San Juan Ltd	P	U
Caracota	Empresa Minera Unificada S.A. (EMUSA)	P	U
Chilcobija	EMUSA	P	U
Churquini	Churquini Enterprises Inc.	P	U
Espiritu Santo	EMUSA	TC	U
La Salvadora	Churquini Enterprises Inc.	TC	U
Rosa de Oro	Empresa Minera Bernal Hermanos	P	U
Canada: Lake George	Consolidated Durham Mines & Resources Ltd.	TC	U
Italy: Manciano[3]	SAMIM S.p.A.	TC	S
Mexico: Wadley	Cía, Minera y Refinadora Mexicana S.A.	P	U
Morocco:			
Timerhdoudine	Soc. des Travaux et de Recherches Miniere	P	U
Tourtit	...do	TC	U
South Africa, Republic of:			
Consolidated Murchison Ltd.	Consolidated Murchison Ltd	P	U
Thailand:			
Bo Thong[3]	Mine Organization Co	P	S
Doi Ngoem[3]	Prasit Mining Co	P	S
Mae Ta[3]	P.T. Smeltering	TC	S
Turkey:			
Turhal-Tokat	Ozdemir Antimony Mine Ltd	P	U
United States:			
Stibnite Hill	U.S. Antimony Corp	TC	U
Yellow Pine	Ranchers Exploration and Development Co.	TC	S

[1]N = not producing as of January 1984; P = producing as of January 1984; TC = temporarily closed.
[2]S = surface; U = underground. For deposits not producing, mining type is proposed.
[3]Not included in availability analysis.

The total demonstrated and inferred resources from Latin America were estimated at 400,000 mt of contained antimony. The demonstrated resources accounting for 24 pct of the total, are estimated to contain 95,500 mt Sb.

Consolidated Durham Mines & Resources Ltd., the only primary antimony producer in Canada, operates the Lake George Mine. The property is currently closed because of the depressed state of the antimony market. The demonstrated resource at the Lake George Mine is estimated to contain 32,100 mt Sb, with 20,500 mt Sb considered to be recoverable (*2*).

SAMIM, a government-owned company, controls the Manciano antimony mining properties in Italy, which comprise five mining units. The current working units are the Montauto and the Tafone, while Salaioli and San Martino sul Fiora are being pilot tested. Macchia Casella has a large resource, though the property is still considered an explored prospect. At present, all these units are under care and maintenance.

Antimony resources in Morocco (Africa) come from two underground mines, the Timerhdoudine and Tourtit. Drilling programs on both properties are expected to increase the known current resources.

CML of the Republic of South Africa has seven mines: Athens, Gravelotte, Monarch, Mulati, United Jack, Weigel, and Free State. CML is the second largest MEC producer after Bolivia. Production from these operations supplies almost 24 pct of the MEC annual requirements. Gold is a significant byproduct at these operations.

Three mining properties were studied in Thailand, two operating mines and one under care and maintenance. Although the current resources are small, additional resources in the area are highly probable. Recent geological and geochemical surveys conducted in the mining areas indicated extensive mineralized areas, but exploration drilling has yet to prove the anomalies.

Ozdemir Antimony Mines Ltd., the largest antimony producer in Turkey, controls the Turhal's six mining units. At present, only four of the mining units have resources on a demonstrated level; the other two are under exploration.

Only two properties in the United States were analyzed—the Stibnite Hill and Yellow Pine Mines. Resources from seven small deposits (Wild Rose, Stampede Lode, Antimony Peak, Quien Sabe, Fencemaker, Coeur d'Alene antimony mine, and Antimony Canyon) were not included in the analyses, since the properties are either mined out, have a very small resource, or have too low a resource grade to be economically extractable at this time.

Table 7.—Antimony resources
(Metric tons)

Location	In situ: Resources, Demonstrated	In situ: Resources, Inferred	In situ: Contained antimony, Demonstrated	In situ: Contained antimony, Inferred	Estimated recoverable antimony as metal[1]
Africa	7,922,000	4,467,000	229,400	128,500	153,000
Asia-Australia	1,830,000	1,598,000	74,600	58,000	51,000
Latin America	1,640,000	6,662,000	95,500	304,400	69,000
North America	2,388,000	193,000	50,100	6,900	31,000
Others[2]	846,000	2,815,000	50,000	475,700	0
Total	14,626,000	15,735,000	499,600	973,500	304,000

[1]From demonstrated resources.
[2]Mines in Italy and Thailand that do not produce refined antimony metal as end product.

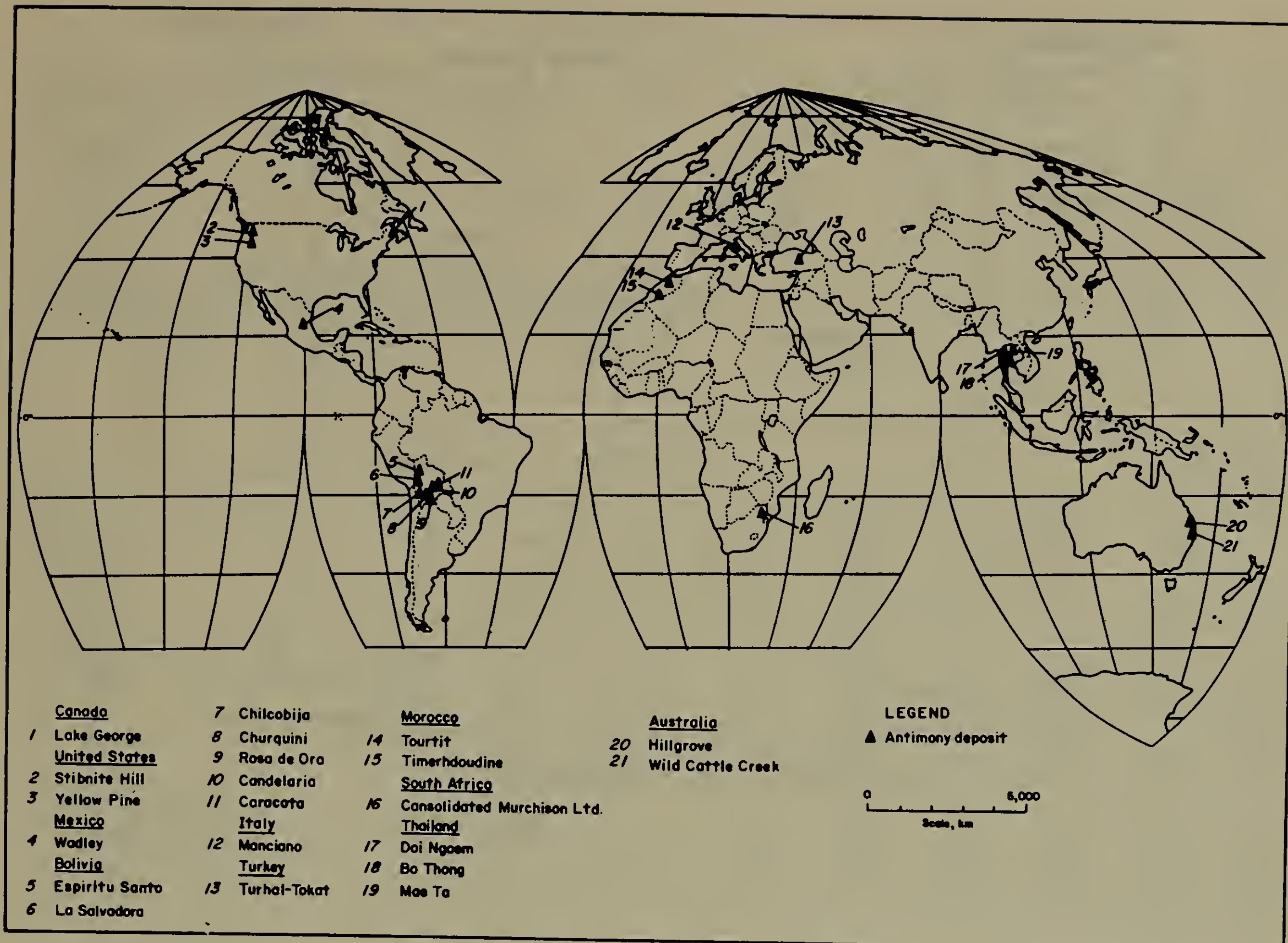

FIGURE 1.—Antimony mine and deposit locations.

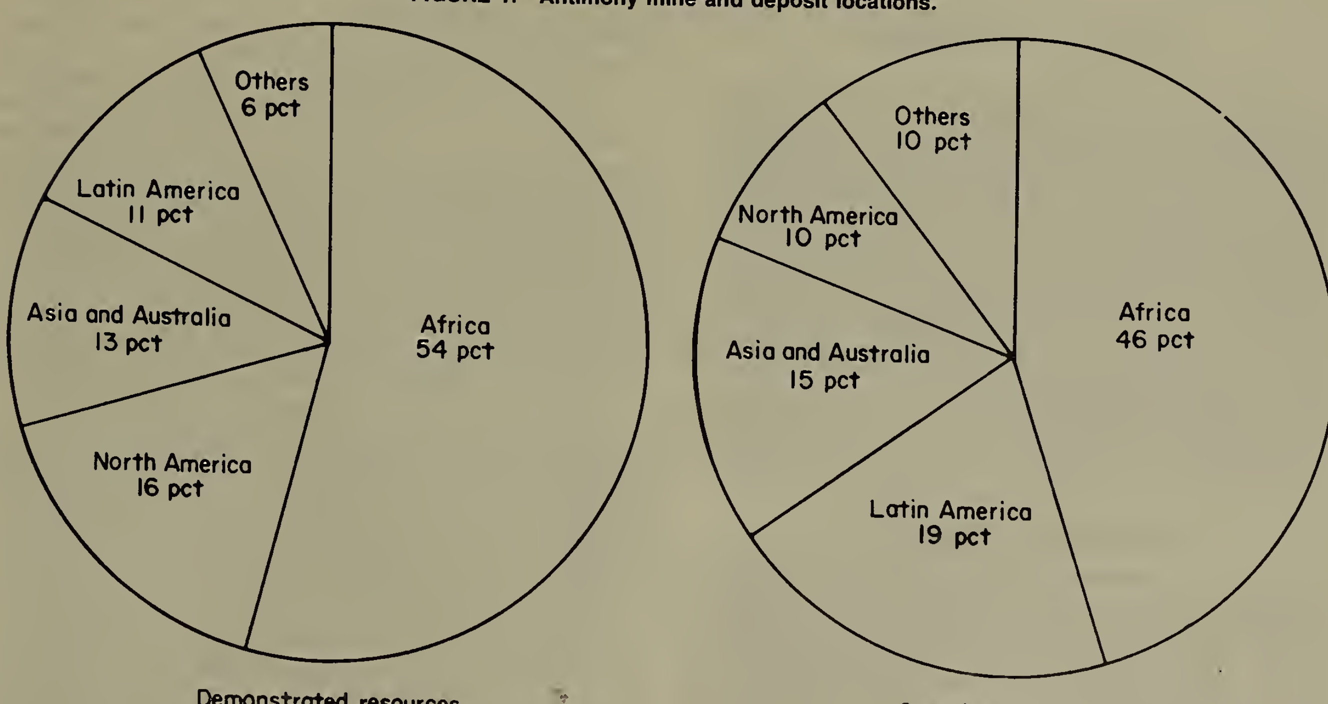

FIGURE 2.—Demonstrated antimony resources.

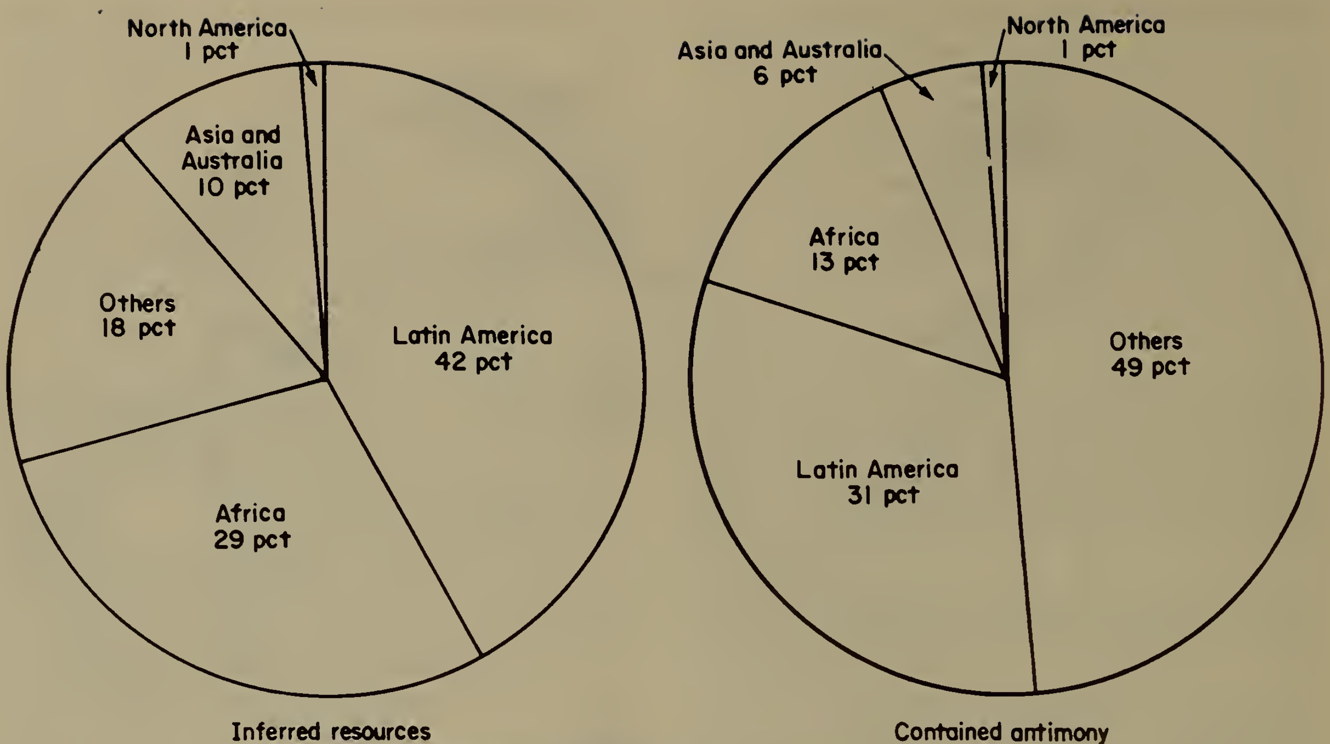

FIGURE 3.—Inferred antimony resources.

BYPRODUCT ANTIMONY

In addition to the primary antimony resource, antimony is also recovered as a byproduct from the smelting and refining of lead and silver ores. The recovery of byproduct antimony in most cases is incidental to the recovery of the primary metals. A major domestic source of byproduct antimony is the Sunshine Mine. The reason Sunshine Mine produces antimony is that the presence of antimony is deleterious to silver refining. Most often antimony contained in lead ores (domestic and foreign) is not paid for by the smelters, because of its negative effect in processing the primary lead. As a result, the antimony resource base from this source is hard to define.

At present, any estimate of byproduct antimony would be hypothetical. Some historical production data are shown in table 8.

SECONDARY ANTIMONY

Secondary antimony provides a large portion of the total antimony supply in most industrialized countries. In general, the recovery of secondary antimony is incidental to the recovery of the principal metal. The largest single source of secondary lead is antimonial lead battery scraps. Other sources are bearing metal, babbitt metal, and lead dross. Depending upon the degree of purity of the scrap metal, the plants either resmelt the scrap or produce a specification material through the addition of lead, tin, or antimony (*6*). Antimony derived from this source is normally consumed in secondary alloy production.

Secondary antimony has always been an important part of total U.S. antimony supply. Historically, this resource contributes between 30 and 60 pct of the total (*6*). However, the introduction of the lead-calcium (maintenance-free) batteries in the automotive industry will reduce the recycling resources. The maintenance-free batteries, aside from taking a major portion of the battery industry, presented problems in the collection system that would insure the complete segregation of the antimonial lead and lead-calcium batteries. Complete separation of these scraps is necessary, since mixed scrap, in certain circumstances, poses problems of toxicity to workers at secondary smelters. When wet, mixed scraps could cause the release of two highly toxic gases, arsine and stibine. A portion of the calcium content in mixed scrap of lead-calcium and antimonial lead oxidizes during the smelting; some forms a very stable compound of antimony (Ca_3Sb_2), making the recovery of antimony extremely difficult. The presence of antimony in lead-calcium alloys used in battery grids causes gassing, which seriously reduces the characteristics of maintenance-free batteries. These problems create difficulties for both the secondary smelters and the battery manufacturers. Hence, it is highly probable that large percentages of battery scraps will not be recycled. Under such circumstances, the secondary resource is highly weakened. Production of secondary antimony in the United States over the last 10-yr period is shown in table 9.

Table 8.—Antimony produced as byproduct at primary lead refineries in the United States, 1975–81
(Thousand pounds)

Year[1]	1975	1976	1977	1978	1979	1980	1981
Gross weight of ores and scrap	12,058	13,486	15,114	11,036	7,500	1,942	7,844
Antimony content:							
Domestic ores[2]	536	710	1,196	1,078	416	36	722
Foreign ores[3]	364	684	336	324	142	24	370
Scrap	234	66	268	164	40	0	18
Total	1,134	1,460	1,800	1,566	598	60	1,110
Antimony content...pct of gross weight	9.4	10.8	11.9	14.2	8.0	3.1	14.2

[1]1982-84 figures have been withheld to avoid disclosing company proprietary data.
[2]Includes primary residues and small quantity of antimony ore.
[3]Includes foreign base bullion and small quantities of foreign antimony ores.

Table 9.—Secondary antimony produced in the United States by kind of scrap and form of recovery, 1975-83
(Thousand pounds)

	1975	1976	1977	1978	1979	1980	1981	1982	1983
New scrap:									
Lead base	3,810	4,232	8,074	8,064	9,426	5,358	4,206	3,322	2,892
Tin base	78	52	48	72	30	32	4	4	2
Total	3,888	4,284	8,122	8,136	9,456	5,390	4,210	3,326	2,894
Old scrap:									
Lead base	32,014	35,284	53,052	44,742	38,830	34,382	35,488	29,856	25,506
Tin base	26	30	28	34	24	14	14	10	8
Total	32,040	35,314	53,080	44,776	38,854	34,396	35,502	29,866	25,514
Grand total	35,928	39,598	61,202	52,912	48,310	39,786	39,712	33,912	28,408
Form of recovery:									
In antimonial lead	29,536	32,996	53,160	43,240	40,734	33,936	32,742	29,206	25,328
In other lead alloys	6,374	6,588	8,026	9,636	7,548	5,820	6,952	3,974	3,046
In tin base alloys	18	14	16	36	28	30	18	12	34
Total	35,928	39,598	61,202	52,912	48,310	39,786	39,712	33,192	28,408

MINING AND PROCESSING TECHNOLOGY

MINING

Antimony deposits are small, irregular, and discontinuous ore bodies that often present problems in ore extraction. Efficient exploitation by large-scale mining operations is limited. In some cases, mining of antimony ore is accomplished by unsystematic hand operations, such as in Thailand. Where the deposit or vein structure warrants the use of large-scale mining operations, mining methods such as open pit, cut and fill, sublevel stoping, shrinkage, and open stoping are used.

Cut and fill is primarily practiced in underground antimony mines in Bolivia. Using overhand mining, the ore is cut in slices parallel to the level. After each cut of ore is mined, backfill is introduced to support the walls. Blasting is performed with an ammonium nitrate-fuel oil (ANFO) mixture with 60 pct dynamite as primer. About 1.0 to 2.6 kg of explosives is required to fragment 1 mt ore.

The sublevel stoping method is practiced in some antimony mines that were studied. This method requires a minimum ore body width of 6 m in order to permit long-hole drilling techniques. In the Tourtit Mine, sublevels are driven from raises, where long-holes are ring-drilled. The ore is blasted with 5 pct ANFO, requiring about 0.35 kg of explosives to fragment 1 mt ore.

Mining in some antimony mines is accomplished by a shrinkage mining method. Basically, this method is an overhand stoping system and is applied mostly in steeply dipping ore deposits. During the entire mining period, a portion of the ore is accumulated until the stope is completed. In a typical mining operation, as in the Timberhdoudine Mine (Morocco), drilling is accomplished by jacklegs with ANFO as the primary explosive. About 0.5 kg of explosives is used to fragment 1 mt ore.

Several antimony mines use open stoping methods to extract ore. This mining method is commonly applied to stratiform deposits. CML in the Republic of South Africa and the Turhal Mine in Turkey utilize open stoping where the width of the vein is less than 3 m. Average explosive consumption is estimated at 0.85 kg to fragment 1 mt ore.

Surface mining is practiced in Thailand and Italy. The Manciano Mine in Italy and Doi Ngoem Mine in Thailand are open pit operations, where benches are maintained and drilling and blasting are required to fragment the ores. This operation requires about 0.3 kg of explosives to fragment 1 mt ore. The other mines in Thailand extract ore by unsystematic surface mining methods. The ore is ripped by bulldozers, and the exposed ores are hand picked. Oversize boulders are broken by hammer and hand loaded into trucks. These operations do not maintain benches, nor do they use explosives to fragment the ore.

ORE PROCESSING

Run-of-mine ores, except direct shipping grades (5 to 25 pct Sb), are generally upgraded to marketable products through crushing, grinding, and classifying processes. Beneficiation of antimony sulfide ores is normally accomplished by gravity and flotation processes. Antimony from simple ores, those that contain only stibnite and siliceous materials, are easily concentrated to about 65 pct Sb with the use of flotation reagents such as copper sulfate or lead nitrate for an activator and xanthate for a collector (7). Beneficiation of complex antimony ores generally employs a flotation process along with gravity concentration to recover the byproducts.

Oxidized antimony ores have not been successfully floated. In Mexico, oxidized ores are normally upgraded by either hand sorting or hand jigging.

SMELTING

Extraction of antimony from ore or concentrate is accomplished by either pyrometallurgical or electrometallurgical methods. Due to the ease of volatilizing oxide ores as well as reducing both sulfide and oxide ores to metal, pyrometallurgical extraction methods have been used more than electrometallurgy. Antimony metal and antimony trioxide can be produced in the same pyrometallurgical plant by merely changing the quantities and types of fluxing agents. Where oxide ores are volatilized, a special type of roaster is adopted in the process. The electrometallurgical technique is not discussed in this report since it is not used in general commercial application.

Smelting antimony ores and concentrates to recover antimony dominates the industry owing to the relative ease of the extraction technique. The important characteristics of antimony that favor smelting include the low melting and boiling point of the metal, high vapor pressure, thermal dissociation, oxidation-reduction reactions, rate of chemical reactions, and the equilibrium established during the process (7).

Antimony is smelted in blast furnaces in two distinct temperature reaction zones. At the initial stage of smelting, stibnite melts and trickles down the charges. As the molten sulfide reaches the temperature zone of 1,332° F, a portion of the molten sulfide is vaporized and carried upward by the blast. Upon reaching a temperature of 2,012° F, thermal dissociation to elemental antimony occurs. Simultaneously, oxidation of the vapors to SO_2 and Sb_2O_3 take place. Metallic antimony not vaporized or oxidized is collected periodically in the forehearth. Vaporized antimony passes through the furnace into the flue where it is cooled down. Upon cooling, the condensate is collected in the baghouse. The collection of a large volume of fumes and dusts is necessary to realize high recovery. The entire process recovers about 85 pct of the antimony content as Sb_2O_3 and 10 pct as metallic antimony; the rest is lost in processing.

Several variations are available in the antimony smelting process. One of them is the precipitation technique. The process takes advantage of the greater affinity of sulfur for iron than for antimony. The smelting is accomplished by mixing fine iron scrap in the furnace charge. The iron reduces the stibnite to metallic antimony wth an iron sulfide matte.

Products from smelters are impure antimony oxides and metal. To attain a commercial grade, the intermediate products are refined to desired products.

REFINING

Refining is accomplished either by a pyrometallurgy process or by electrorefining. Basically, pyrometallurgy could refine the impure metal or the antimony oxide to the desired final product; i.e., in times of high metal demand, antimony oxide is readily converted to pure metal and vice versa. In electrorefining, the process starts with impure metal and produces pure metal as the final product.

Pyrometallurgical refining operations in most cases are carried on in a small reverberatory furnace. Refining begins with the charging and melting of impure antimony metal. Upon melting, a mixture of soda and coke dust is added to produce thick slag. In about 3 h, the slag is skimmed off. The impurities of iron and sulfur are then removed by adding chemical reagents such as oxysulfide of antimony and potash. The final slag, referred to as "star slag" and principally made up of antimony glass, contains 20 to 60 pct Sb (7). After about 15 min, the antimony metal, called regulus, is ladled out into molds where a starlike pattern is formed on the metal surface. The starred regulus usually is over 99.6 pct Sb (7).

Electrolytic refining starts by casting the impure metal into anodes. Once the anodes are submerged into the aqueous bath, the antimony is dissolved into the solution. By means of electrolysis, the antimony is redeposited on the cathode. The impurities, generally composed of sulfur, iron, copper, arsenic, gold, and silver, are collected in the cell slimes. When present in appreciable quantities, arsenic and copper codeposit with antimony in the cathode. Copper is normally removed from the electrolyte by cementation on powdered metallic antimony, but arsenic tends to concentrate in the electrolyte. Because distillation can only remove part of the arsenic from the electrolyte, antimony cathodes always contain a small amount of arsenic. Complete arsenic removal is possible by resmeltng the cathode with an oxidizing slag composed of caustic, sodium nitrate, and soda ash, which removes arsenic as sodium arsenate. The starred regulus metal produced normally is over 99.9 pct Sb (7).

DEPOSIT EVALUATION PROCEDURE

Illustrated in figure 4 is the Bureau's Minerals Availability program (MAP) evaluation process, from deposit identification to the development of availability curves. This flowsheet shows the various evaluation stages used in this study to assess the availability of antimony from individual properties. After a deposit is identified for analysis, engineering and economic evaluations of the property are performed. For nonproducing deposits optimal mining and concentrating rates and other production parameters were chosen using current standard engineering principles. Startup dates for developing deposits were based on announced company plans. For explored deposits, a near-term

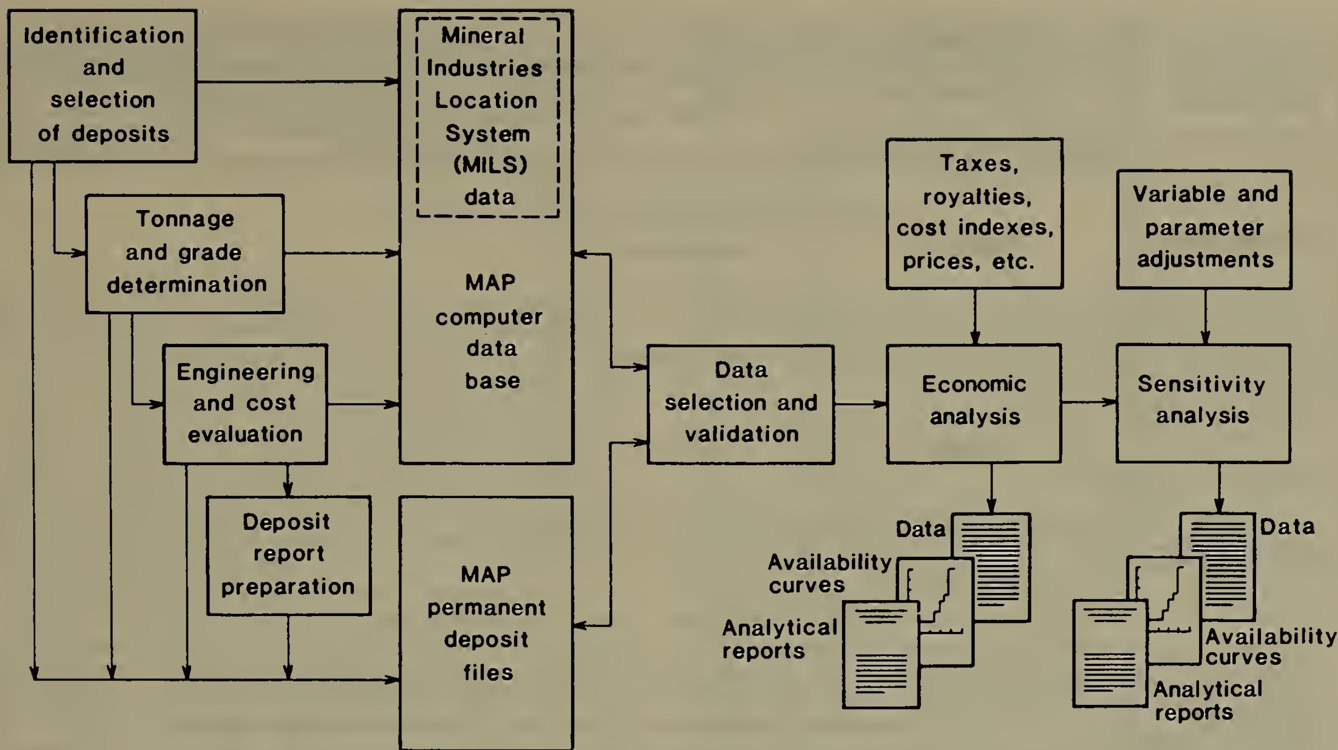

FIGURE 4.—Minerals availability program deposit evaluation procedure.

development schedule (5 to 10 yr) was chosen. Planned expansions for operating mines were included when known.

Information on average grades, ore tonnages, and different physical characteristics affecting production was obtained from various sources, including Bureau of Mines and U.S. Geological Survey publications, professional journals, State and industry publications, company annual reports, 10K reports and prospectuses filed with the Securities and Exchange Commission, private companies, and estimates made by Bureau personnel. Much of the foreign data was collected through a Bureau contract with Brown and Root Development, Inc., Houston, TX.

Selection of deposits was limited to known deposits that contain at least 85 pct of the demonstrated reserves and resources located in each country as of January 1984. Reserves are material that can be mined, processed, and marketed at a profit under prevailing economic and technological conditions. Resources are concentrations of naturally occurring solid, liquid, or gaseous materials in the Earth's crust in such form that economic extraction of a commodity is currently or potentially feasible (*8*).

For the deposits analyzed, tonnage estimates were made at the demonstrated resource level based on the mineral resource-reserve classification system developed jointly by the Bureau and the U.S. Geological Survey (*8*). The demonstrated resource category includes measured plus indicated tonnages, as shown in figure 5. Generally, reserve and resource tonnages and grade calculations presented in this study were computed from specific measurements, samples, or production data and from estimations made on geologic evidence.

The objective of the study is to include mines and deposits that account for at least 85 pct of the antimony production and known resources from each significant producing country.

The engineering and economic analyses for each deposit was performed to determine the total cost necessary to produce a specified level of output from the deposit. Total cost, also called commodity or incentive price, is defined as the average total cost of production for the deposit. In this study, profit computed at a 15-pct discounted-cash-flow rate of return (DCFROR) was included in the total cost. Total cost, then, is the antimony price (in constant 1984 U.S. dollars) at which the firm would recover its capital investment and make a 15-pct profit.

Determination of the quantity of antimony that could be produced and the cost required to achieve this production was based on the following assumptions:

1. Each operation will produce at full planned operating capacity throughout its life. (Capacities were based on 1984 and/or 1984 company plans or engineering judgments.)
2. Competition and demand conditions are such that each operation will be able to sell all its output at its total production cost. This condition implies that the level of antimony demand will support the highest cost deposit, or that existing government subsidies will equal the difference between the market price and the total cost for each submarginal deposit.
3. All byproducts will be sold at January 1984 prices.
4. Concentrates produced by the deposits analyzed are processed to refined antimony metal or refined antimony trioxide, the final marketable products. All antimony metal is sold f.o.b. plant.

Time lags involved in filing environmental impact statements and receiving necessary permits, financing, etc., were not included in the analysis. Existing laws and regulations, environmental, political, legal, or other constraints may limit production from some of the deposits included in this study.

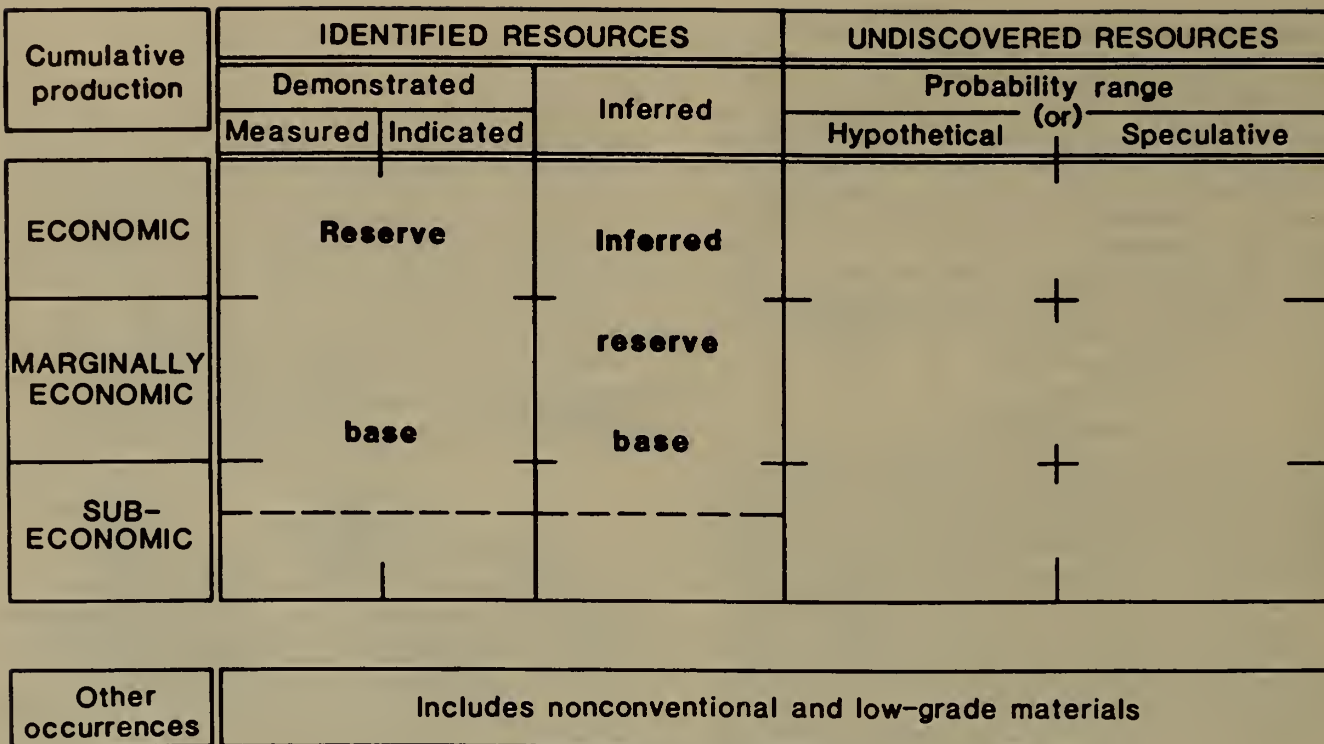

FIGURE 5.—Mineral resource classification categories.

The byproduct prices (gold, $370.89/tr oz) used in this study were based on January 1984 information. Because the study was conducted using constant January 1984 dollars, no escalation of either costs or prices was included.

For each operation included in an economic evaluation, capital expenditures were calculated for exploration, acquisition, development, mine plant and mine equipment, and constructing and equipping the mill. The capital expenditures for the different mining and processing facilities include the costs of mobile and stationary equipment, construction, engineering, infrastructure, and working capital. Infrastructure is a broad category that includes costs for access and haulage facilities, ports, water facilities, power supply, and personnel accommodations. Working capital is a revolving cash fund required for operating expenses such as labor, supplies, insurance, and taxes. All costs were in U.S. dollar terms.

The initial capital costs for producing or past producing mines have been depreciated according to the actual investment year, and the undepreciated portion was treated as a capital investment in 1984, the year of costs for this evaluation. Reinvestments will vary according to capacity, production life, and age of the facilities. Where appropriate, costs have been updated to January 1984 U.S. dollars according to local currency factors and individual country inflation indexes, weighted proportionately by the impact of labor, energy, and capital in the antimony industry on a countrywide basis.

The total operating cost of a mining project is a combination of direct and indirect costs. Direct operating costs include operating and maintenance labor and supplies, supervision, payroll overhead, insurance, local taxation, and utilities. The indirect operating costs include technical and clerical labor, administrative costs, maintenance of facilities, and research.

When available, actual company cost data were used. If these data were not available, the required capital and operating costs were estimated by standardized costing techniques. In some cases, costs were estimated from the Bureau's cost estimating system (CES) (*9*). This system is designed to prepare a prefeasibility type estimate for capital and operating costs based on an average cost derived from U.S. and Canadian mining operations. Index value for each cost component allows the system to update cost for time, geographic locations, labor rates, and specific mining and milling conditions. Correct use of CES usually generate costs within ±25 pct of the actual cost.

After production parameters and costs for the development of antimony deposits were established, the supply analysis model (SAM) (*10*) was used to perform various economic evaluations pertaining to the potential availability of antimony. The SAM system is a comprehensive economic evaluation simulator that is used to determine the constant-dollar long-run price at which the primary commodity must be sold to recover all costs of production, including a prespecified DCFROR on investment, less all byproduct revenues. The DCFROR is the ROR that makes the present worth of cash flows from an investment equal to the present worth of all after-tax investment (*11*). The rate of 15 pct was considered the minimum return on investment sufficient to attract new capital to the industry. Some government-owned operations utilize criteria other than economics to justify continued operation. However, for comparison purposes, each deposit was analyzed at 15-pct DCFROR.

The SAM contains a separate tax records file for each State and country that includes all the relevant tax parameters under which a mining firm would operate. These tax parameters are applied to each mineral deposit under evaluation with the implicit assumption that each

deposit represents a separate corporate entity. In reality, properties belonging to the same corporation would have certain tax advantages not assumed for this evaluation. Other costs in the analysis include standard deductibles such as depreciation, depletion, deferred expenses, investment tax credits, and tax loss carryforwards. The SAM also contains a separate file of economic indexes to allow for updating all cost estimates for producing and nonproducing operations.

CAPITAL AND OPERATING COSTS

Capital costs for 21 properties, 12 producers, and 9 nonproducers and past producers were evaluated. Since all producing mines have been in production for a number of years, almost all investments have already been depreciated. Any current and future investments incurred by these operations are limited to equipment replacement cost or cost of expansion if any. Capital investments to reopen the nonproducing mines (past producers) are limited to rehabilitation costs and therefore do not reflect the same costs encountered in developing virgin deposits. As a result, capital cost data are not presented in this report.

The average total operating costs calculated for each of the deposits analyzed included mining, milling, transportation, taxes, smelting and refining, and byproduct credit; these costs are presented in table 10. Mine and mill operating costs include all costs for labor, energy, supplies, and indirect costs of administration, maintenance, overhead, and insurance. The "other costs" category includes recovery of capital and a 15-pct DCFROR on invested capital. Operating costs often vary greatly, depending on such factors as size of operation, mining method, deposit location, stripping ratio, depth of ore body, grade of ore, processing losses, energy and labor costs, and applicable tax structure. The costs presented in this section are based on mining and milling the ore over the life of the operation.

As shown in table 10, the mine operating costs vary from \$11.18/mt to \$42.67/mt ore. The difference in cost is mainly because of the mining method used in the operations. The mines in Asia and Australia use expensive underground timbered open stoping or cut-and-fill methods, whereas Latin American mines utilize open cut, open stope, and standard cut and fill. In addition, labor costs in Latin America are much lower than those in Africa and Australia.

In milling operations, Asia-Australia also shows the highest production costs, mainly because of the added cost incurred in the recovery of gold as a byproduct. Gold values, however, are credited to the value of recovered antimony metal. Such values are, however, not offsetting, suggesting that it may not be economical to recover gold. Latin America shows the lowest milling cost, chiefly due to low labor costs. In addition, one mine produces a direct shipping ore, thus incurring no milling cost.

When production cost is converted to dollars per pound of antimony recovered, the United States and Canada have the highest production costs. The high costs are mainly because of expensive labor costs, high taxation, and processing of low-grade ore. Latin America, due to its low labor cost and high-grade ores, shows the lowest production costs for both mine and mill operations.

Costs for African mines reflect their expensive smelter and refining costs. Most African ores are smelted and refined in European countries where labor and energy costs are high. On the other hand, most of the ores in Latin America are smelted and refined in domestic plants.

When byproduct credits are removed from the total operating costs, the Asia-Australia mines become the most expensive operations, chiefly because of their expensive mining methods.

Table 10.—Estimated weighted-average operating and total production costs

	North America	Latin America	Asia and Australia	Africa	Others[1]
Number of mines	3	8	3	3	4
Total recoverable ore ... mt..	2,490,000	1,675,000	1,924,000	7,091,000	849,000
Weighted-average grade ... pct Sb..	1.72	5.14	3.70	2.75	5.84
Total recoverable Sb ... mt..	31,189	69,033	50,980	152,648	NAp
Production costs, \$/mt ore:					
Mine operation	\$11.18	\$13.72	\$42.67	\$28.04	\$12.32
Mill operation	\$11.69	\$6.40	\$15.24	\$10.28	\$9.05
Operating costs, \$/lb Sb in concentrate:					
Mine operation	\$0.40	\$0.15	\$0.73	\$0.59	NAp
Mill operation	.42	.07	.26	.21	NAp
Smelter and refining	.17	.11	.23	.28	NAp
Transportation	.11	.05	.06	.19	NAp
Tax	.26	.09	.06	.09	NAp
Subtotal	1.36	.47	1.34	1.36	NAp
Byproduct credit	(.37)	(NA)	(.13)	(.20)	NAp
Net cost	.99	.47	1.21	1.16	NAp
Other costs[2]	.51	.11	.20	.04	NAp
Total (15-pct DCFROR)	1.50	.58	1.41	1.20	NAp
Total (0-pct DCFROR)	\$.95	\$.48	\$1.29	\$1.06	NAp

NAp Not applicable.
[1]Mines that produce products other than antimony metal.
[2]Includes a 15-pct DCFROR and capital recovery.

When other costs such as a 15-pct DCFROR and capital recovery are added to the net cost, the United States and Canada have the highest production costs. The U.S. and Canadian operations have much higher capital recovery costs than the Latin American operations. In contrast to U.S.-Canadian operations, most Latin American mines have been in operation for quite a long time; therefore, most of their capital investments have been fully depreciated.

Transportation cost reflects the total costs of transporting the mill concentrate to the smelter. These costs may include one or a combination of trucking, railroad transportation, ocean freight, insurance, and handling costs. As shown in table 10, operations in Africa reflect the highest transportation cost, because of the added costs of land and ocean transportation to European smelters, including additional handling and insurance costs, for many African concentrates. Latin America shows the least expensive transportation costs, because large amounts of the concentrates are smelted within relatively short trucking-railroad transportation distances.

Production costs at 0-pct DCFROR reflect what operations could produce at the breakeven level and cover all production costs after applying byproduct credit. Hence, 0-pct DCFROR as shown in the table should not be interpreted as the cash cost equivalent used in the industry.

ANTIMONY AVAILABILITY

After cost and resource data were determined for each selected property, total and annual antimony availability curves were constructed. A total resource availability curve is an aggregate of the total production potential at a stipulated cost that covers full production costs. Individual annual availability curves for (producing and nonproducing) mines were constructed to determine the cost-tonnage relationship of the resources on an annual basis. The curves reflect the antimony capacity of the properties that were studied. For nonproducing properties that were temporarily closed, the time lags required to reactivate the mines depended upon the rehabilitation work needed to bring the property back into production. Of the 21 properties evaluated and costed for this study, three properties from Thailand and one from Italy have been excluded from availability curves. Besides the limited recoverable antimony resources from these properties, the final end product, a crude metal, has a very limited application and is used within the country.

TOTAL AVAILABILITY

At the demonstrated resource level, potential recoverable antimony from market economy countries was estimated at 304,000 mt Sb from 17 properties (figure 6 and table 11). Mines in Africa and Latin America account for 50 and 23 pct, respectively, of the total recoverable antimony (table 11). Producing mines account for nearly 75 pct of this total. In 1984, when antimony metal was selling at an average price of $1.68/lb, approximately 293,700 mt Sb could be produced from MEC's at a 15-pct DCFROR. However, at this price, no U.S. deposit can produce and earn a 15-pct DCFROR.

This economic analysis is limited to resources on a demonstrated level. Although an additional estimated tonnage of 973,500 mt of contained antimony could be available from the inferred resource at some of the deposits, no economic evaluation was performed of this resource.

ANNUAL AVAILABILITY

Table 12 shows the potential annual production capacity from the 17 properties analyzed. Production capacity represents the average annual production in metric tons of antimony metal over the life of the property. Assuming all the properties are in operation, the average annual production from these properties is estimated at 29,200 mt/yr Sb.

Potential annual antimony production from producing mines at various total production cost ranges, including a 15-pct DCFROR, is shown in figure 7. The production levels shown represent the annual antimony output potential at full capacity for the selected total production cost range. For example, in 1984 the capacity potential at a total cost of production of $1.65 or below was estimated at 19,700 mt Sb. The initial rise of the curves in 1985 is due to expan-

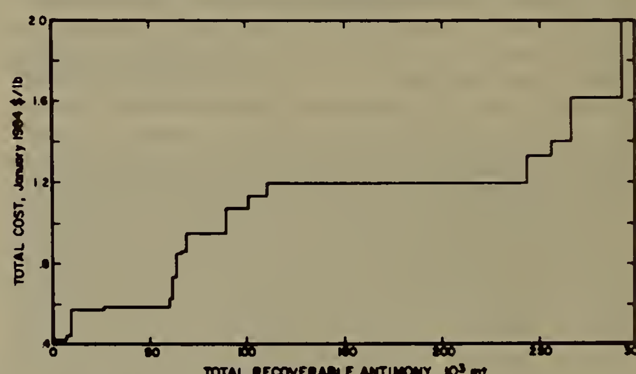

FIGURE 6.—Total recoverable demonstrated antimony resources from producing and nonproducing properties.

Table 11.—Primary antimony potentially available from mines and deposits at selected cost ranges, including a 15-pct DCFROR
(Metric tons)

Antimony price, $/lb	North America	Latin America	Asia and Australia	Africa	Total
Under $0.55	0	9,300	0	0	9,300
$0.56 to $1.15	20,500	59,800	11,700	9,700	101,700
$1.16 to $2.00	500	0	39,300	142,900	182,700
$2.01 to $3.00	10,300	0	0	0	10,300
Total	31,300	69,100	51,000	152,600	304,000

Table 12.—Primary annual production capacity for primary antimony at a 15-pct DCFROR
(Metric tons)

Antimony price, $/lb	North America	Latin America	Asia and Australia	Africa	Total
Under $0.55	0	2,800	0	0	2,800
$0.56 to $1.15	2,300	6,500	2,900	1,000	12,700
$1.16 to $2.00	200	0	1,400	11,200	12,800
$2.01 to $3.00	900	0	0	0	900
Total	3,400	9,300	4,300	12,200	29,200

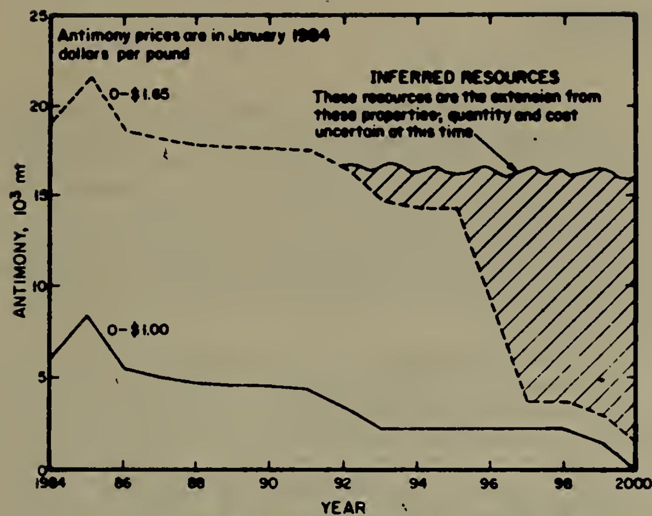

FIGURE 7.—Potential annual availability from producing properties at a 15-pct DCFROR.

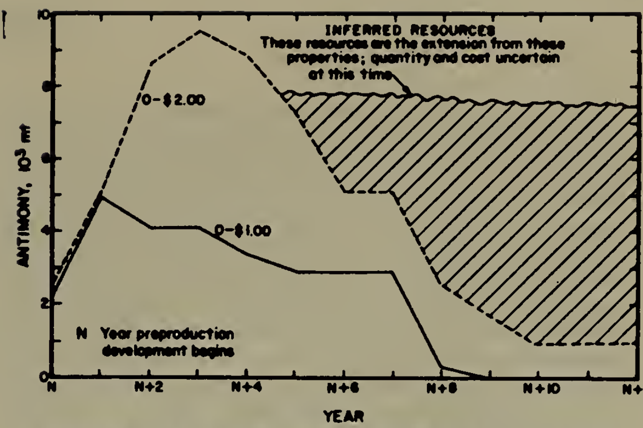

FIGURE 8.—Potential annual availability from nonproducing properties at a 15-pct DCFROR.

sion of capacity at one mine. The subsequent declines in the curves mark the depletion of the demonstrated resources from four mines. At this time, it is expected that the inferred resources will be upgraded to the demonstrated level, probably at a price much higher than the prices prevailing in January 1984. This is because most of the inferred resources have lower grades and are at greater depth factors that would increase production costs. Figure 7 shows the probable availability of antimony from inferred resource. If the price were to increase, incentives to search for and explore new deposits would take effect.

Annual availability curves for nonproducing mines were based on the assumption that rehabilitation work would begin in year N, because startup dates were not known. (See figure 8.) These curves indicate that lead time would be required before any production could occur. The nonproducing properties could contribute 9,500 mt Sb annually at a total production cost ranging from $0.56 to $3/lb (table 13). The demonstrated resources from these nonproducing mines and the number of productive years are small, unless the inferred resources are geologically and economically reevaluated and upgraded to the demonstrated level.

The producing mines have a total capacity of 19,700 mt/yr Sb. The total production costs for operating mines range from $0.55/lb to $2/lb, with an average cost estimated at $0.97/lb Sb. Assuming a production cost of $0.55/lb Sb, 2,800 mt/yr Sb would be available from two producing mines in Latin America. At production costs up to $1.15/lb Sb, additional capacity of 5,300 mt/yr Sb would be available from four producing mines, three in Latin America and one in Africa. At production costs up to $2/lb Sb, the three producing properties (CML, Hillgrove, and Turhal-Tokat) would contribute additional capacity of 11,600 mt/yr Sb.

Assuming (demonstrated level) the total mine capacity of 29,200 mt/yr Sb from producers and nonproducers is consumed each year, the potential recoverable antimony from MEC's would be depleted in 11 yr. The available resource at a price of $1.15/lb Sb would be depleted in 4 yr. Considering domestic resources, at a mining capacity of 1,100 mt/yr Sb, the total potential recoverable resources would last for 10 yr. However, if production capacity has to increase to fill the domestic requirement, the same recoverable resource would be depleted in less than a year. This mine life, however, can be offset if the inferred resources are geologically and economically reevaluated and found to be feasible for mining. Another possibility is to discover new deposits.

Table 13.—Distribution of potential annual capacity from producers and nonproducers at a 15-pct DCFROR

Antimony price, $/lb	North America	Latin America	Asia and Australia	Africa	Total
		PRODUCERS			
Under $0.55	0	2,800	0	0	2,600
$0.56 to $1.15	0	4,300	0	1,000	5,300
$1.16 to $2.00	0	0	1,400	10,200	11,600
$2.01 to $3.00	0	0	0	0	0
Total	0	7,100	1,400	11,200	19,700
		NONPRODUCERS			
Under $0.55	0	0	0	0	0
$0.56 to $1.15	2,300	2,200	2,900	0	7,400
$1.16 to $2.00	200	0	0	1,000	1,200
$2.01 to $3.00	900	0	0	0	900
Total	3,400	2,200	2,900	1,000	9,500

CONCLUSIONS

The United States, with two nonproducing primary antimony properties as of 1984, has 10,700 mt of recoverable antimony or about 3.5 pct of the total recoverable resources contained in the properties evaluated in MEC's. Production capacity from these two domestic properties is estimated at 1,100 mt/yr Sb or 3.7 pct of total MEC annual capacity. This domestic production capacity represents 9.9 pct of the total domestic industrial requirements of 11,081 mt/yr Sb, averaged over a 10-yr period. However, antimony prices well above those prevailing in January 1984 would be required in order for these deposits to be economically available.

At a total production cost of $1.15/lb, 111,000 mt Sb could be profitably recovered from MEC's primary mines. At the prevailing January 1984 price of $1.68/lb, nine properties (all producing mines at the time of study) could produce profitably. At this price, no domestic property could recover antimony economically. If the price were to increase to $2/lb, an estimated additional 182,700 mt Sb would be available from producing and nonproducing mines. One domestic property would be able to operate profitably. The remaining resource of 10,300 mt Sb would be available at a total production cost between $2/lb and $3/lb.

The United States, with its high degree of industrial activity, normally imports and consumes 30 to 50 pct of the total annual mine production from the MEC's. With such a small percentage of the MEC's resources located in the United States, the United States will probably continue to rely on foreign antimony to satisfy domestic industrial requirements. The most probable sources of U.S. antimony supply are Mexico, Bolivia, the Republic of South Africa, and China.

Even though byproduct and secondary antimony supply a major part of the antimony production, these sources were not analyzed because there is no definable resource base as previously explained. The three properties in Thailand that were not included in the availability curves were projected to produce only crude antimony metal (72 pct Sb), which is used in Thailand. One property in Italy producing impure antimony as a fill-in for a battery recycling plant is also not included in the availability curves.

To gain a better understanding of the total availability, byproduct and secondary antimony must be studied and analyzed.

REFERENCES

1. Roskill Information Services Ltd. The Economics of Antimony. 5th ed., 1983, 140 pp.

2. Industrial Minerals (London). Antimony—Price Recovery as Production Falls. No. 198, Mar. 1984, pp. 37-51.

3. Plunkert, P. A. Antimony. Ch. in Mineral Facts and Problems, 1985 Edition. BuMines B 675, 1985, pp. 33-42.

4. Miller, M. H. Antimony. Ch. in United States Mineral Resources. U.S. Geol. Surv. Prof. Paper 820, 1973, pp. 45-49.

5. Dana, E. S. and W. E. Ford. A Textbook of Mineralogy. Wiley, 4th ed., Mar. 1932, pp. 442-443, 445, 448, 453, 477.

6. National Materials Advisory Board. Trends and Usage of Antimony. Natl. Acad. Sci., Washington, DC, NMAB-274, Dec. 1970, 113 pp.

7. U.S. Bureau of Mines. Materials Survey—Antimony. MS-1, Mar. 1951, pp. I-9 and IV-29.

8. U.S. Bureau of Mines and U.S. Geological Survey. Principles of a Resource/Reserve Classification for Minerals. U.S. Geol. Surv. Circ. 831, 1980, 5 pp.

9. Clement, G. K., Jr., R. L. Miller, P. A. Seibert, L. Avery, and H. Bennett. Capital and Operating Cost Estimating System Manual for Mining and Beneficiation of Metallic and Nonmetallic Minerals Except Fossil Fuels in the United States and Canada. BuMines Special Publ., 1980, 149 pp. Also available as—STRAAM Engineers, Inc. Capital and Operating Cost Estimating System Handbook—Mining and Beneficiation of Metallic and Nonmetallic Minerals Except Fossil Fuels in the United States and Canada (contract JO255026). BuMines OFR 10-78, 1977, 382 pp.

10. Davidoff, R. L. Supply Analysis Model (SAM): A Minerals Availability System Methodology. BuMines IC 8820, 1980, 45 pp.

11. Stermole, F. J. Economic Evaluation and Investment Decision Methods. Investment Evaluation Corp., Golden, CO, 2d ed., 1974, 443 pp.

THE LIBRARY OF CONGRESS

THE LIBRARY OF CONGRESS

INFORMATION CONSERVATION, INC.

NOV.-DEC. 1986

LIBRARY OF CONGRESS
0 002 955 948 A